ARO Basic Research for the Soldier

Dr. Stephen Lee
Chief Scientist
US Army Research Office

Research Funding by State

- >$10M
- >$5M<$10M
- >$2M<$5M
- <$2M
Mission:

- The U.S. Army Research Office mission is to seed scientific and far reaching technological discoveries that enhance Army capabilities.
- The primary ARO program provides basic research that responds to the Army’s operational requirements.
Army Research Office Overview

Utilize the vast intellectual capital of our nation’s universities to:

- Exploit Scientific Opportunities for Revolutionary New Army Capabilities
- Drive Science to Develop Solutions to Existing Army Technology Needs
- Accelerate Transition of Basic Research
- Strengthen University, Industry, Government Partnerships
- Educate and Train the Future S&E Workforce for the Army

Research Thrusts

- Chemistry
- Materials
- Computing & Info Science
- Mathematics
- Electronics
- Mechanics
- Environmental Science
- Network Science
- Life Sciences
- Physics

Research ranges from atom optics for underground bunker/tunnel detection to nano-energetics for more powerful and insensitive munitions and propellants.
**Return on Investment (Understanding & Performance)**

- **Need Driven Research** – emphasis on improving specific capabilities or overcoming identified technology barriers
- **Opportunity Driven Research** - emphasis on developing and exploiting scientific breakthroughs to produce revolutionary new capabilities

**Balanced Basic Research Portfolio**

*Must Address Both Opportunity Driven Research and Need Driven Research*
• **Extrapolation of Existing Technologies *(Need Driven)*
  - Incremental, Continued Improvement in Existing Technologies
  - Often Driven or Enabled by **Commercial** Market
    - CPU on a chip
    - Inexpensive GPS
  - May be a “Disruptive Technology” (e.g. personal vs. mini computers)

• **Revolutionary New Applications from Scientific Breakthroughs *(Opportunity Driven)*
  - Utilizes Two Somewhat Distinct Mechanisms
    - Fundamentally new approaches to solving old problems
    - Fundamentally new capabilities
  - Examples from Past
    - **Navigation** - Satellites and atom clocks for GPS
    - **Range Finders** and **Target Designators** - Lasers
  - Examples for the Future
    - Atom Optics for Jam-Proof Navigation
    - Quantum Informatics for Computation, Secure Communication, Imaging
    - Nano-energetics for propellants and explosives
    - Micro-active flow control
“None of the most important weapons transforming warfare in the 20th century - the airplane, tank, radar, jet engine, helicopter, electronic computer, not even the atomic bomb - owed its initial development to a Doctrinal Requirement or request of the military.”


The details of this provocative quote can be debated; but it in any case, it is absolutely clear that RDEC and stakeholder input is critical for:

• Transitioning basic research
• Identifying needs-driven basic research
• And identifying revolutionary science/engineering
• Exploit scientific opportunities for revolutionary new capabilities
• Apply science to generate solutions to existing needs
• Prevent technological surprises
• Accelerate the transition of research to application
• “Honest Broker” for the Army for objective assessments
• Leverage S&T of outside sources for Army benefit
• Strengthen university, in-house, industry partnerships
• Foster S&E training in disciplines critical to the Army
• Enhance outreach efforts for greater intellectual diversity
Army Research Office Organization

- Director
  - Operations Directorate
    - Support Management
    - Information Management
    - Acquisition Center
  - Physical Sciences
    - Physics
    - Chemistry
    - Life Sciences
  - Engineering Sciences
    - Mechanical Sciences
    - Materials Science
    - Electronics
    - Environmental Sciences
  - Informational Sciences
    - Mathematical Sciences
    - Computational Sciences
    - Network Science
    - Outreach Programs

~ 100 employees at RTP
45 PhD Program Managers

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Engaging the Extramural Research Community to Focus on Army Problems

Materials Science
- Computational materials science
- Hierarchical materials
- Multifunctional materials

Mathematical Sciences
- Stochastic modeling
- Complex systems
- Visualization

Computational materials science
- Sensors and emitters
- Nanoelectronics
- RF & High Frequency Electronics

Physics
- Optics & image science
- Condensed matter physics
- Quantum information

Chemical Sciences
- Advanced energy conversion
- Energetic materials design
- Synthesis of protective materials

Mechanical Sciences
- Smart structures/Flow Control
- Rotorcraft aeromechanics
- Combustion/Propulsion

Environmental Sciences
- Atmospheric boundary layer
- Habitation science
- Hydrology & geomorphology

Life Sciences
- Neurophysiological/Cognitive Neurosciences
- Bio-engineering, -degradation, -remediation
- Molecular Biology of Performance

Electronics
- Sensors and emitters
- Nanoelectronics
- RF & High Frequency Electronics

Engaging the Extramural Research Community to Focus on Army Problems

Computing & Information Sciences
- Autonomous Systems
- Networked Systems
- Information Security

Extramural Basic Research

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Single Investigator (SI)
- ~$110K/yr for 3 yr periods
- Continually open BAA Solicitation
- ~120 new grants/year
- All States, >240 Universities

Battlefield Centers of Excellence
- Limited to HBCUs
- New competition in FY09
- ~$200K per year

Centers of Excellence
- Materials Center - 6.1 Basic Research
- High-Performance Computing Center - 6.1 Basic Research
- Flexible Displays Center - 6.2 Applied Research
- No New COEs Planned

HBCU/MI ARO Core Grants
- Topics from ARO BAA
- ~110K/yr for 3 yr periods

STIR
- $50K Limit
- Short-term, proof-of-principle rsch
- Part of SI Continual BAA Solicitation

DEPSCoR
- For states receiving least amt of federal funds
- 3 year support
- Annual BAA Solicitation

STIR
- $50K Limit
- Short-term, proof-of-principle rsch
- Part of SI Continual BAA Solicitation

MURIs
- ~$1.25M per year
- 3 year period
- 10 new initiatives annually
- Annual BAA Solicitation

UARCs
- 4 consortia (ISN, ICB, ICT, IAT)
- 5 year efforts
- ~$5 – 10M per year
- No new UARCs anticipated

SBIR/STTR
- Small Business Research
- Phase I and Phase II efforts
- www.armysbir.com for more information
• Extremely Technical and Scientifically Competent PMs
  – Most program managers are adjunct faculty researchers
  – PMs oversee proposals in same discipline they perform research

• RTP’s Proximity to Leading Universities
  – Three universities are of the highest caliber
  – RTP is often compared to Silicon Valley with more than 100 R&D facilities existing within the RTP and employing over 37,600 employees

Only U.S. location with greater concentration of top schools - Cambridge/Boston MA

Cost of living comparison
Durham, NC $100,000 income
Cambridge, MA $179,703 income

Source: Nat’l Assoc. of Realtors, 2004

**Single Investigator Program**

**Leverages World-Class Academic Expertise**

- Rapid and agile exploitation of novel science opportunities world-wide
- Extremely cost-effective
- All states and D.C.
- >250 institutions
- Graduate students supported: ~1400
- ~900 university grants, $112k/yr grant

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**6.1 Dollars**

$57M
Includes MURI, DURIP, PECASE

Multi-Disciplinary University Research Initiative (MURIs)
• Research vital to the Army, but applicable to multiple Services

• Investigates high priority, transformational topics such as biologically inspired mobile networks of autonomous vehicles, self-assembling multifunctional ceramic composites

• Critical mass of researchers; $1.25M/year, 5-years

• Approximately 10 new initiatives started annually

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University Affiliated Research Centers (UARCs)
University Led with Industry Partnership(s)

Electrodynamics & Hypervelocity Physics
Immersive Environments
Soldier Survivability
Biotechnology

$M FY08 FY09 FY10 FY11 FY12
61104 29.5 35.0 33.6 35.4 37.7

Optoelectronic fiber-device covering for ID and line-of-sight IR communication
Bio-Inspired Materials for Lightweight Portable Energy

Relevant MLPs
Sensing
Power & Energy
Survivability
Human Dimension
Lethality
Battle Command

High intensity focus on emerging opportunities

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Accelerating the pace of Army Transformation through biotechnology

Bio-inspired materials and energy

Biodiscovery tools

Biomolecular Sensors

UCSB
Caltech
MIT

Cognitive Neuroscience

Bio-inspired network science

Armor

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Dramatically improving soldier survivability through nanotechnology.
Collaborative Technology Alliances
Industry-Led Partnerships with Universities and the Army

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FUTURE CTA INVESTMENTS
- Topics Under Consideration
  - Robotics (continuation)
  - Sensor and Information Fusion
  - Cognition and Neuroergonomics
- Proposed Commencement FY10

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
### University Centers of Excellence

University Researchers Focused on Army Interests Over Long Term

- **Battlefield Capability Enhancement Centers**
  - Cooperative Agreement – 5 Efforts
  - HBCU/MI lead with TRADOC Battle Lab Collaboration
  - Focus on rapid transition of basic research
  - $500K/year efforts
  - New 5 yr program starts beginning FY09

### University Centers of Excellence

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**High Perf Computing**

**Flexible Displays**

**C2 Decisionmaking**

**Extremities Protection**

**Battlefield Communications**

**Sensor Fusion**

**Materials**

**Complementary programs cohesively managed within ARL and across RDECOM**

**TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**
ARO’s Basic Research Role Connectivity

**Financial Backers**: DARPA, AF/Navy, DTRA, DDR&E, JPM/JPEO

**Research Performers/Transition Partners**: Army, DARPA, ARL Directorates, Corps’ Engineer Center, Army Medical Labs, ARI, RDECs, Industry

**ARO**

- Provides support to University Affiliated Research Centers, Single Investigators, Industry
- Facilitates collaboration and technology transitions with Army, DARPA, DDR&E, JPM/JPEO

**Technology Driven, Warfighter Focused**
Propulsion & Energetics Program
Hydrocarbon Combustion Thrust

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Hydrocarbon Combustion Thrust Detail

**Scientific Objectives:**
- Kinetics & Combustion
  - Kinetic Model & Theory Development
  - Reduced Models
  - Surrogate Fuel Development
- Sprays & Flames
  - Spray development, ignition, burning, emissions, soot
  - Engine models

**Scientific Opportunities:**
- Novel diagnostics (long test time shock tubes, high pressure flat flame burners for condensed fuels, ballistic imaging)
- New paradigms/theories for kinetic system development
- Cyber-infrastructure

**Army Impact/Relevance:**
- Computationally efficient & predictive engine design models
- Future fuel flexibility
Approach

Barriers

• Lack of accessibility to high pressure, high temperature (Burning)

• Lack of accessibility to high pressure, “low” temperature (Ignition)

• Lack of kinetics for complex chemistry

• Inability to image in dense near field in sprays

• Fuel composition

Methods/Techniques

• Pressure vessel combustion experiments

• Long (20+ms) test time ignition apparatus

• Reduced model technique development

• Ballistic Imaging techniques

• Surrogate Fuel development
Hydrocarbon Combustion Thrust Detail (cont’d)

Collaborations/Leveraging

- TARDEC
- ARO-CH
- AFRL/AFOSR, RZ
- FAA
- NIST
- ONR
- SEDD
- NSF
- DoE

ARO-EN
Academia/Industry

SME for DARPA BioFuels Program
5 PI/Govt Joint Publications

Collaborative Funding

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
28-29 April 2009

Chemical Sciences Review

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Vision

To develop an understanding of the mechanisms that govern electrochemical redox reactions and transport of species such as electrode, catalysis, electrolyte, and interfaces to ultimately provide advanced sensors, batteries, fuel cells, and technology not yet foreseen to the soldier.

Research Thrusts

1. Redox Chemistry/Electrocatalysis
2. Transport of Electroactive Species

![Diagram of electrochemical cell components: plunger, glass, O-ring, electrolyte, working electrode, 25μm spacer, window.]

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Redox Chemistry/Electrocatalysis
Scientific Objectives

- To understand how material and morphology effect electron transfer and electrocatalysis
- To develop robust chemical models that enable design of tailored electrodes and electrocatalysis
- To discover new spectroscopic and electrochemical techniques to be able to probe surfaces and species on those surfaces
Scientific Opportunities

• Sum frequency generation IR spectroscopy for in-situ investigation of surfaces and interfaces

• New X-Ray absorption spectroscopy techniques

• New Ab initio treatments of electrocatalytic systems

Novel PtAuRu/Ru alloys for methanol oxidation
Redox Chemistry/Electrocatalysis
Army Impact and Relevance

- Power Storage and Generation
- Sensors
- Chem/Bio Defense

Future Soldier Concept
Protonex Fuel Cell
Current Chem/Bio Gear

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Barriers

- Lack of techniques to probe surfaces directly without interference from bulk material.
- Lack of robust models to describe complex electrocatalysis materials and electrodes with heterogeneous surfaces and complex morphologies.
- Lack of understanding of activation of adsorbed species on catalyst and electrode surfaces.

Methods/Techniques

- Development of new spectroscopic, electrochemical and microscopy methodologies such as delta micro EXAFS, SFG IR, etc.
- New atomic level simulations with improved computational methodologies to describe the “fundamental properties” of complex materials and surfaces.
- Generation and characterization of controlled model electrode systems using single crystals, ion implantation, and SPM.
Transport of Electroactive Species
Scientific Objectives

- To develop an understanding for the mechanisms of transport through polymers and electrolytes
- To design new tailor able electrolytes based on new polymers and ionic liquids
- To explore new methodologies to selectively allow transport of species
- To develop new computation approaches to model transport in heterogeneous charged environments

Computational model to describe process of proton dissociation and transport in polymer electrolytes, Greg Voth, University of Utah
Scientific Opportunities

- New computational approaches (atomistic and multiscale) simulations of polymers
- Discovery of new Metal Organic Framework (MOFs) synthetic strategies
- Discovery of new solid acid, ceramic, and polymeric conductive materials

Multi-scale model to describe proton transport mechanisms and hydrated polymer morphology; Stephen Paddison, University of Tennessee
Transport of Electroactive Species
Army Impact and Relevance

Army Impact and Relevance

- Power Storage and Generation
- Electrosynthesis and degradation
- Printable Electronics and displays

Flexible Display

Future soldier with sustained power use of up to 100W

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Transport of Electroactive Species

Approach

Barriers

• Lack of understanding of interplay between morphology and conductivity of polymers

• Lack of understanding of ionic liquid structure property relationships

• Lack of understanding about how charged species move in heterogeneous environments

Methods/Techniques

• New computational approaches to determine effects of hydration and polymer structure to conductivity

• New experimental efforts using NMR, Voltammetry, x-Ray diffraction, Interfacial tension to study ionic liquid properties

• New computational and spectroscopic techniques to study and predict transport complex surroundings
New Areas

• Catalysis in Alkaline Environments
  ➢ Disruptive Fibers for Flexible Armor (MURI; proposal recommended)
  ➢ Fibers - 1 single investigator grant started
  • Ion Transport In Complex Heterogeneous Organic Materials (MURI, pending MURI)

Increasing Emphasis

• Nanoscale morphology/catalysis
• Reemphasizing basic research (resisting pull to more applied)

Decreasing Emphasis

• Research on reforming hydrocarbons